Simple testing can prevent most critical failures

-- An analysis of production failures in distributed data-intensive systems

Ding Yuan, Yu Luo, Xin Zhuang, Guilherme Rodrigues, Xu Zhao, Yongle Zhang, Pranay U. Jain and Michael Stumm

University of Toronto

Code and dataset:
http://www.eecg.toronto.edu/failureAnalysis/

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Key findings

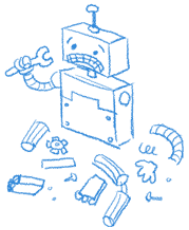
- Failures are the results of complex sequence of events
- Catastrophic failures are caused by incorrect error handling
  - Many are caused by a small set of trivial bug patterns
- *Aspirator*: a simple rule-based static checker
  - Found 143 confirmed new bugs and bad practices

Distributed system failures can be deadly

amazon.com

Oops!

Amazon AWS outage downs Reddit, Quora, Foursquare, Instagram, NetFlix, and about 70 other sites.

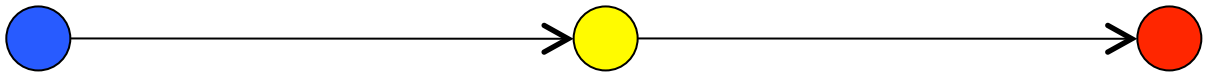


Google outage: Internet traffic plunges 40%.

Facebook goes down; users called 911.

A thorough analysis of real-world failures

- Study end-to-end failure propagation sequence



Fault (root cause), e.g., bug, h/w fault, misconfiguration, etc.

Error (exception), e.g., system-call error return

Failure, visible to user/admin.

  - Reveal the minimum conditions to expose failures
  - Reveal the *weakest link*
- Previous works only studied elements in isolation

Study methodology

- Randomly sampled 198 user-reported failures*
  - Carefully studied the discussion and related code/patch
  - Reproduced 73 to understand them
- 48 are catastrophic --- they affect all or a majority of users

Software	Program language	Sampled failures	
		Total	Catastrophic
Cassandra	Java	40	2
HBase	Java	41	21
HDFS	Java	41	9
Hadoop MapReduce	Java	38	8
Redis	C	38	8
Total	-	198	48

* Analysis of each failure can be found at: http://www.eecg.toronto.edu/failureAnalysis/

Outline

- Failures are the results of complex sequence of events

- Catastrophic failures are caused by incorrect error handling
  - Many are caused by trivial bugs

- *Aspirator*: a simple rule-based static checker

An example

User: "Sudden outage on the entire HBase cluster."

Event 1: Load balance: transfer Region R from slave A to B

↓

Slave B opens R

Event 2: Slave B dies

↓

R is assigned to slave C

↓

Slave C opens R

```
/* Master: delete the
 * ZooKeeper znode after
 * the region is opened */
try {
  deleteZNode();
} catch (KeeperException e) {
  cluster.abort("…");
}
```

Not handled properly

Finding I: *multiple* events are required

77% of the failures require more than one input events

Only occur on long-running system (38%)

Event 1: *Load balance: transfer Region R from slave A to B*

Slave B opens R

Event 2: *Slave B dies*

R is assigned to slave C

Slave C opens R

```
/* Master: delete the
 * ZooKeeper node after
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```

Finding II: event order matters

Order of events is important in 88% of the multi-events failures

Event 1: Load balance: transfer Region R from slave A to B

Slave B opens R

Event 2: Slave B dies

R is assigned to slave C

Slave C opens R

```
/* Master: delete the
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```
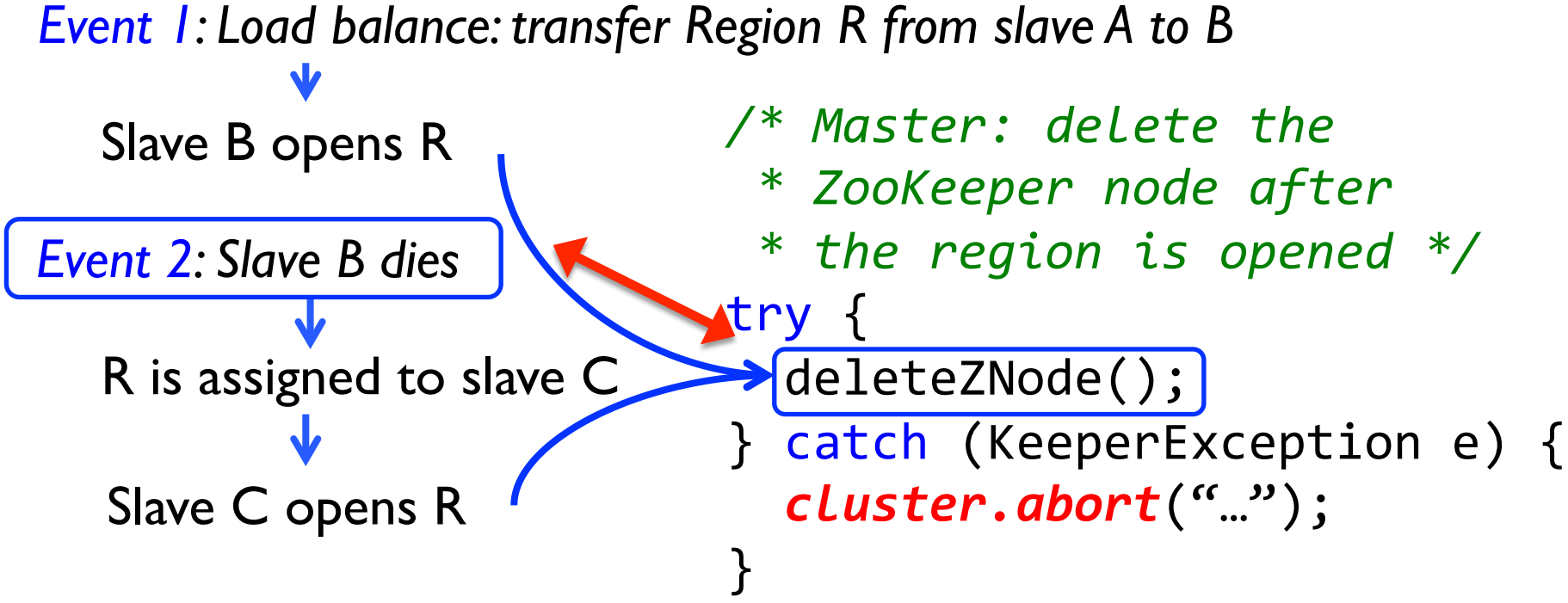

Finding III: timing matters

26% of the failures are non-deterministic

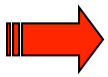


Complexity is not surprising

- These systems undergo thorough testing
  - Must provide unit test for every patch
  - Use static checker on every check-in
  - Use fault injection testing [HadoopFaultInjection]
- Designed to provide high availability
  - E.g., automatic failover on master failures

Outline

- Failures are the results of complex sequence of events



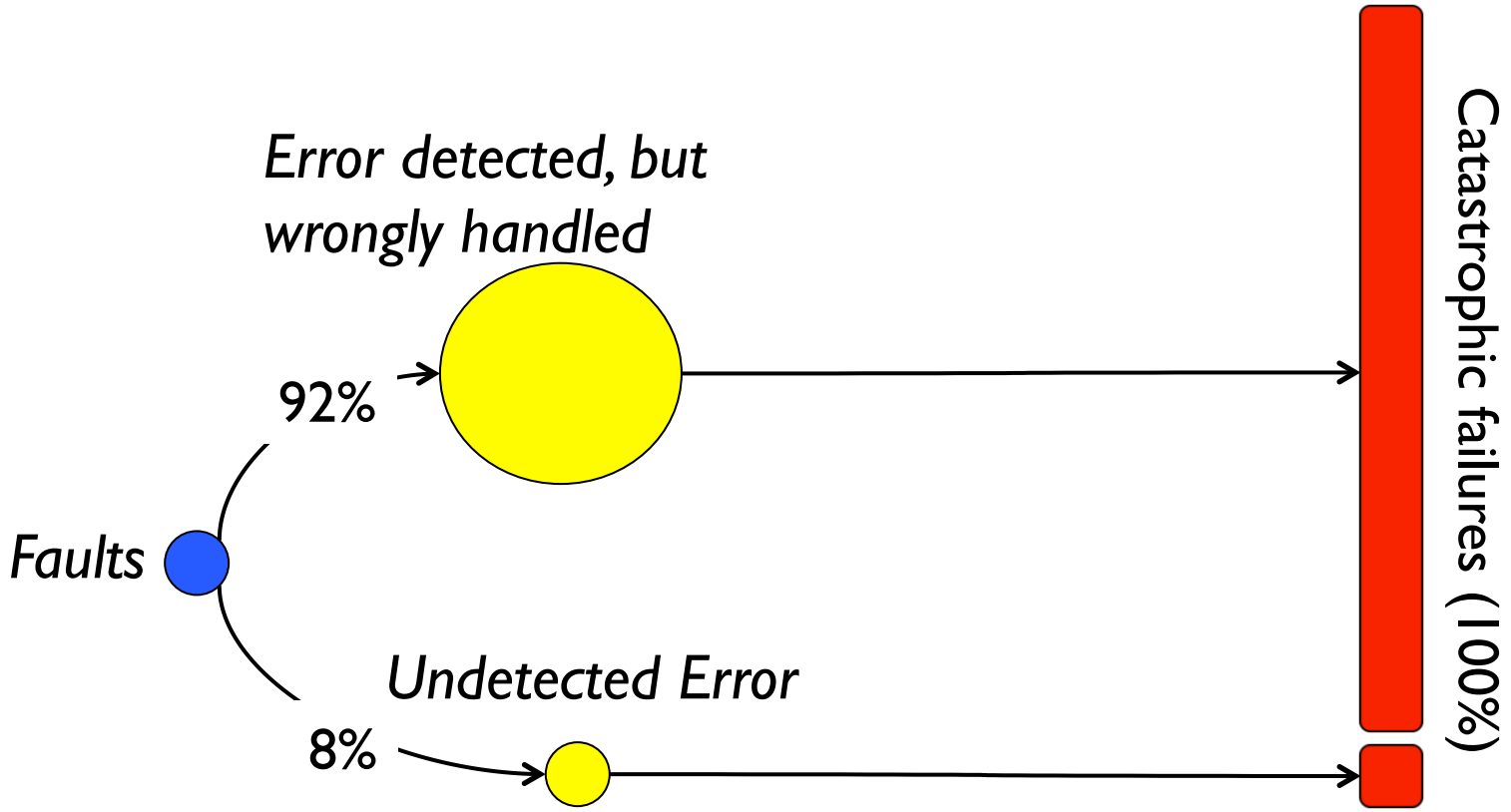
- Catastrophic failures are caused by incorrect error handling
  - Catastrophic failures: those affect all or a majority of the users

- *Aspirator*: a rule-based static checker

Breakdown of catastrophic failures

92% of catastrophic failures are the result of incorrect error handling

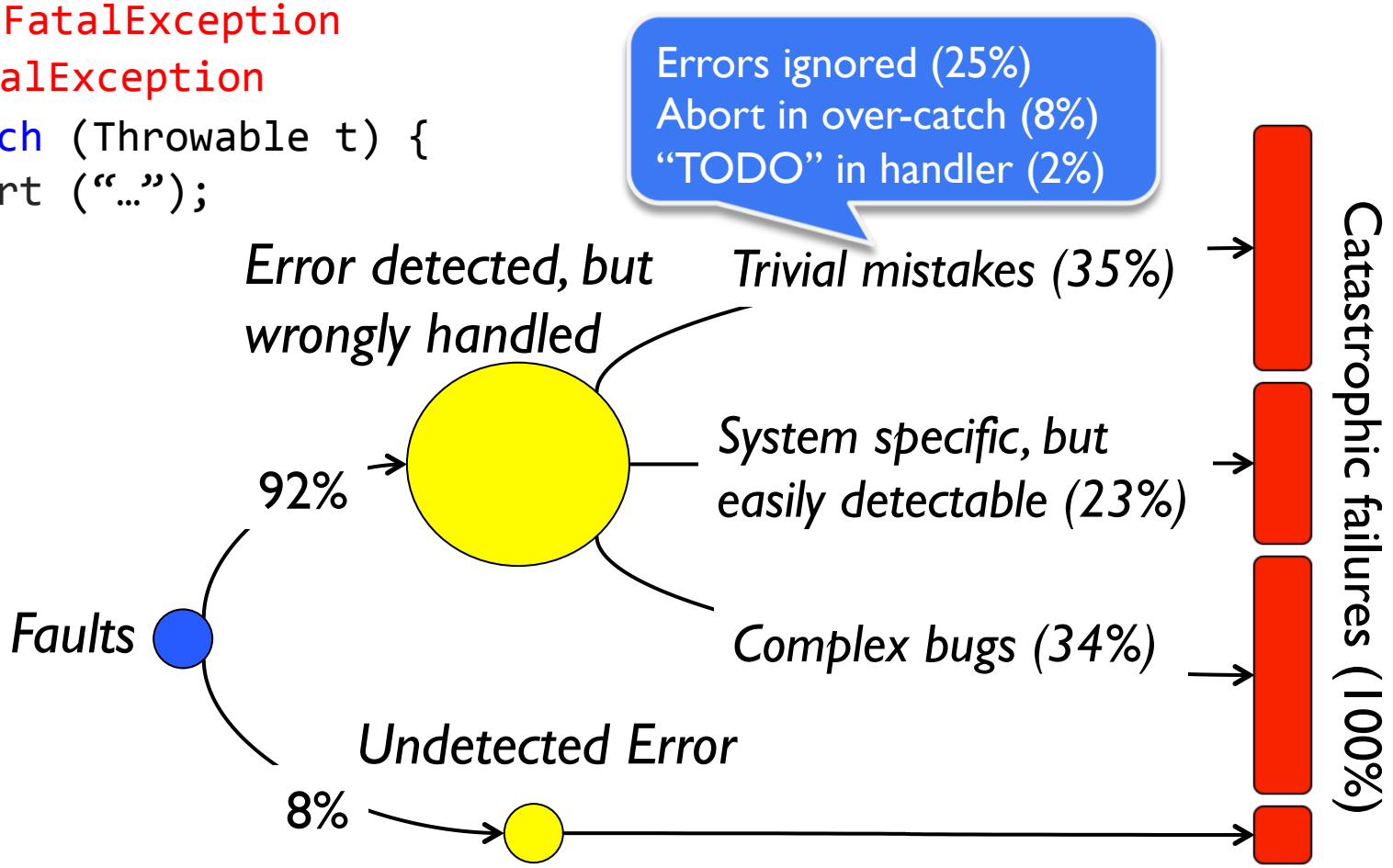
- Error handling code is the *last line of defense* [Marinescu&Candea'11]



Trivial mistakes in error handling code

Example of abort in over-catch

```
NonFatalException
FatalException
} catch (Throwable t) {
abort ("…");
}
```



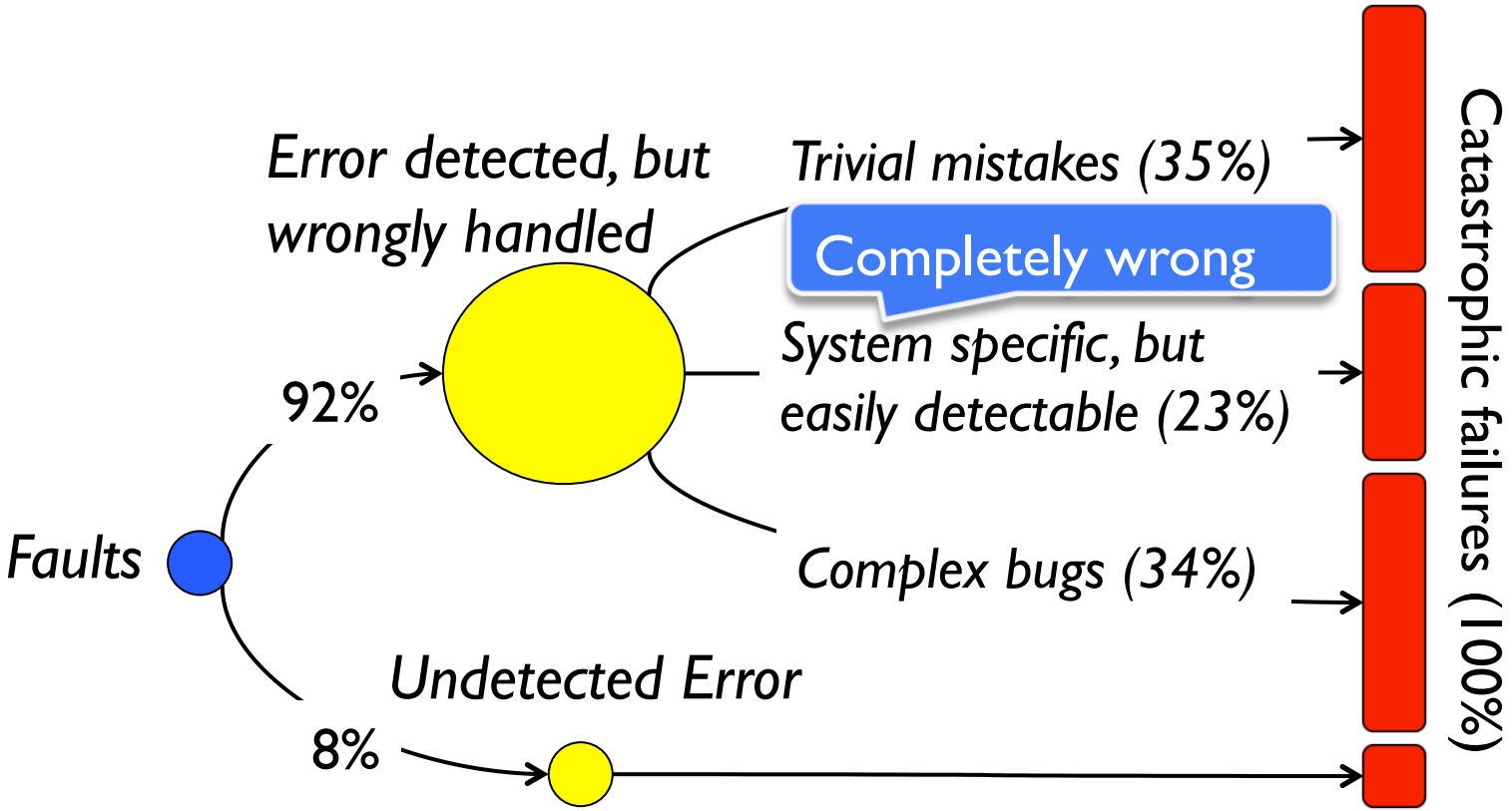
A failure caused by trivial mistake

User:

"MapReduce jobs hang when a rare Resource Manager restart occurs. *I have to ssh to every one of our 4000 nodes in a cluster and kill all jobs.*"

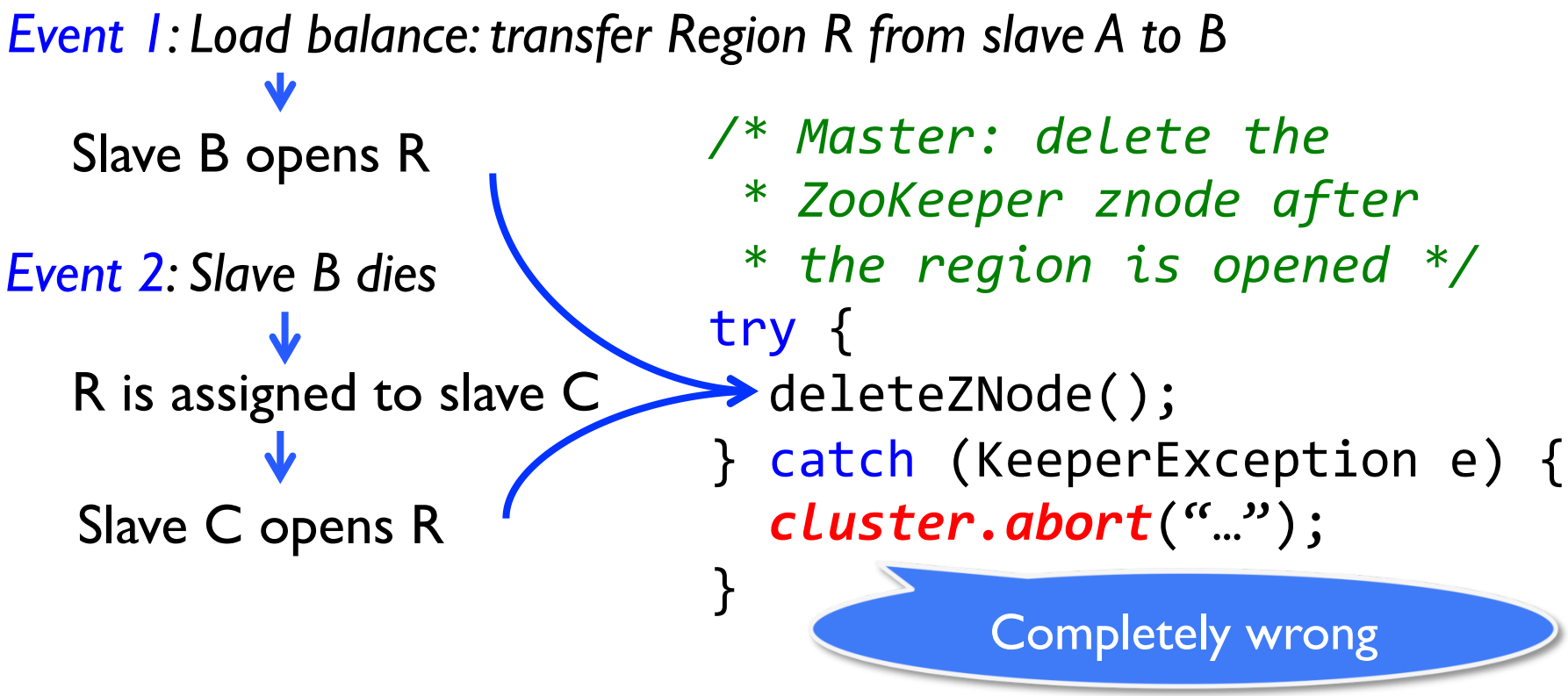
```
catch (RebootException) {
  // TODO
   LOG("Error event from RM: shutting down...");
+ eventHandler.handle(exception_response);
}
```

Easily detectable bugs

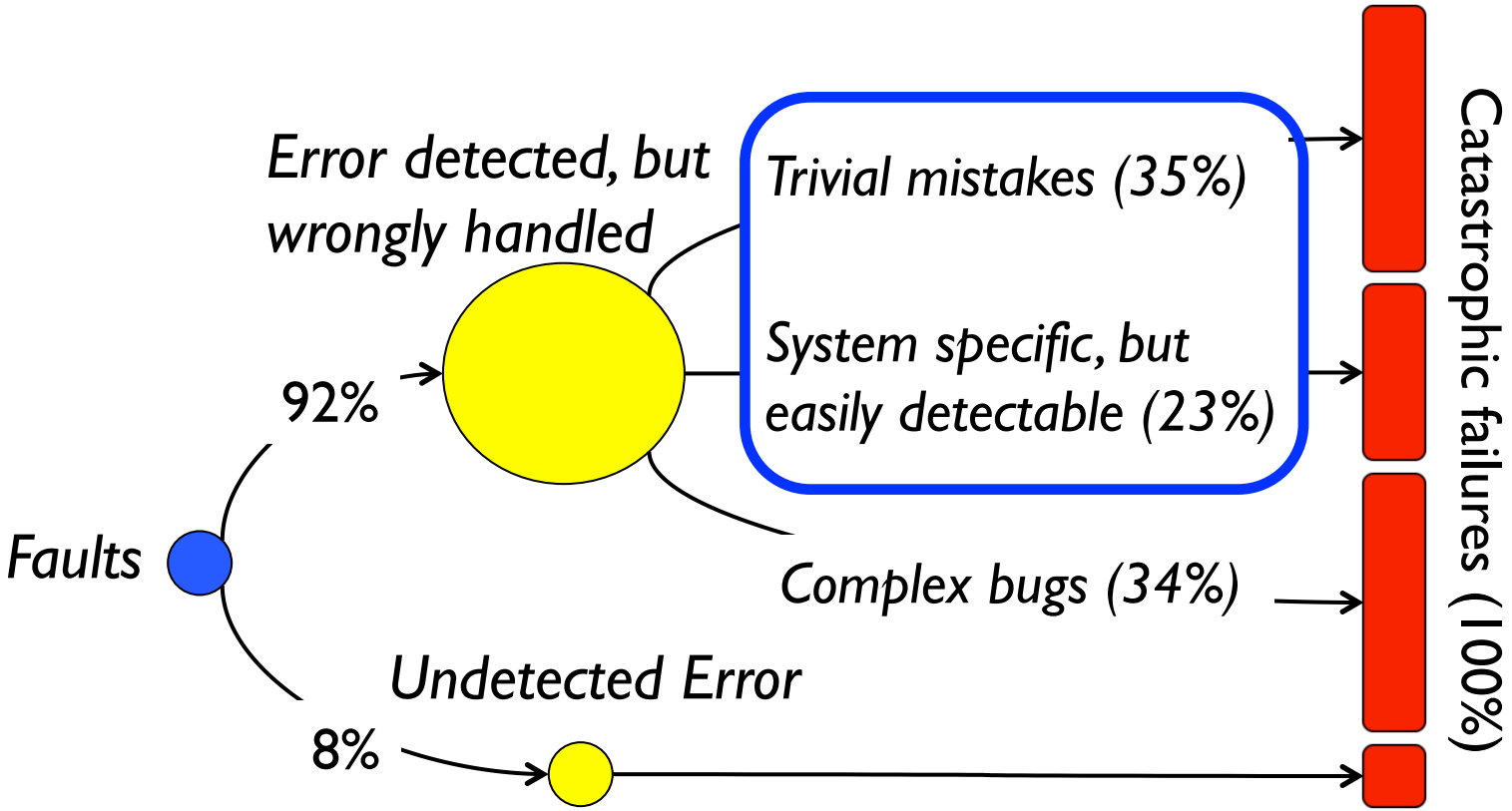


The HBase example: an easily detectable bug

- Difficult to be triggered; easily detectable by code review



Over half are trivial or easily detectable bugs



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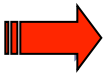

Aspirator: a simple rule-based static checker

Aspirator: a static checker for Java programs

- Three rules on exception handling
  - Not empty
  - Not abort on exception over-catch
  - No "TODO" or "FIXME" comment
- False positive suppression techniques (details in paper)

- Over 1/3 of catastrophic failures could have been prevented
  - If aspirator has been used and identified bugs fixed

All source code of aspirator is at: http://www.eecg.toronto.edu/failureAnalysis/

Checking real-world systems

new bugs in every system

	System	*Bugs*	*Bad practice*	*False positive*
Training set	Cassandra	2	2	9
	HBase	16	43	20
	HDFS	24	32	16
	Hadoop MapRed.2	13	15	1
Testing set	Cloudstack	27	185	20
	Hive	25	54	8
	Tomcat	7	23	30
	Spark	2	1	2
	Zookeeper	5	24	9
	Total	**121**	379	115

New bugs can lead to catastrophic failures

- Hang system

```
try {
  tableLock.release();
} catch (IOException e) {
  LOG("Can't release lock", e);
}
```

- Data loss

```
try {
  journal.recover();
} catch (IOException ex) {

}
```

- Cluster crash
  - E.g., bugs found by "abort in over-catch" check

Mixed feedbacks from developers

- Reported 171 new bugs/bad practices
  - 143 confirmed/fixed; 17 rejected; no response for the rest

"No one would have looked at this hidden feature; ignoring exceptions is bad precisely for this reason"

"I really want to fix issues in this line, because I really want us to use exceptions properly and never ignore them"

"I fail to see the reason to handle every exception."

Why do developers ignore error handling?

- Developers think the errors *will never happen*
  - Code evolution may enable the errors
  - The judgment can be wrong

```
} catch (IOException e) {
  // will never happen
}
```

- Error handling is difficult
  - Errors can be returned by 3rd party libraries

```
} catch (NoTransitionException e) {
  /* Why this can happen? Ask God not me. */
}
```

- Feature development is prioritized

Other findings in the paper

- Failures require no more than 3 nodes to manifest
- Failures can be reproduced offline by unit tests
  - The triggering events are recorded in system log
- Non-deterministic failures can still be *deterministically reproduced*

Related work

- Error handling code is often buggy [Gunawi'08, Marinescu'10, Rubio-González'09, Sullivan'91, etc.]
- Studies on distributed system failures [Gray'85, Oppenheimer'03, Rabkin'13, etc.]
- Distributed system testing [ChaosMonkey, Gunawi'11, Guo'11, HadoopFaultInjection, Killian'07, Leesatapornwongsa'14, Yang'09, etc.]

Conclusions

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Unexpected fun: comments in error handlers

```
/* If this happens, hell will unleash on earth. */

/* FIXME: this is a buggy logic, check with alex. */

/* TODO: this whole thing is extremely brittle. */

/* TODO: are we sure this is OK? */

/* I really thing we should do a better handling of these
 * exceptions. I really do. */

/* I hate there was no piece of comment for code
 * handling race condition.
 * God knew what race condition the code dealt with! */
```

Source code and dataset:
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Thanks!

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